REINFORCEMENT AND LEARNING: THE PROCESS OF SENSORY INTEGRATION

BY HERBERT G. BIRCH

The City College of New York

AND

M. E. BITTERMAN

Cornell University

INTRODUCTION

When Pavlov and Thorndike began their investigations of the learning process, they introduced into psychology two methods of experimentation from which there emerged two diverse conceptions of the mechanisms underlying modifiability. The Pavlovian situation focused attention on the development of stimulus-equivalence (32). The classical conditioning experiment begins with an established stimulus-response relationship, s_1–r_1, and a second stimulus, s_2, which does not elicit r_1. After the repeated presentation of s_2 in conjunction with s_1, s_2 presented alone becomes capable of eliciting r_1. If, after the conditioned relationship has been developed, s_2 is repeatedly presented without s_1, it loses the newly acquired functional property, and extinction is said to have taken place. Observations of this sort led Pavlov to the conclusion that contiguity of stimulation is the essential factor in conditioning which he regarded as a process of afferent modification rather than as a process of stimulus-response connection. Contiguous stimulation, he thought, modifies the cortex in such a way that the excitation aroused by the conditioned stimulus subsequently spreads to the afferent area ordinarily activated by the unconditioned stimulus, and thus *indirectly* elicits the unconditioned response. In the Pavlovian experiments a few rather limited responses were selected as indicators of the course of conditioning, and general activity was restricted by elaborate harness. Under these circumstances Pavlov did not have much opportunity to observe qualitative variations in response and so devoted little consideration to response modification in his learning theory.

Thorndike's investigations of trial and error learning in a sense represented the other side of the behavioral coin. While Pavlov's attention was fixed upon afferent relationships, Thorndike was almost exclusively concerned with action (39). In the problem box, variability of response, the occurrence of an appropriate response, and the fixation of that response are the three events upon which observation is focused (1). An animal, placed in the box, displays a sequence of responses which is terminated by the action which permits exit from the box. In successive trials variability of behavior is diminished, and the response of the animal tends more and more to be restricted to those aspects of the terminal action pattern which are prerequisite to escape from confinement. In order to account for the selection of response appropriate to given motivating conditions and the disappearance of irrelevant responses, Thorndike introduced a primitive need-reduction theory, the now classical law of effect.

The two principles—contiguity and effect—are by no means mutually contradictory, and for some time they were implicitly accepted as comple-

mentary postulates which made it possible to explain, although in an incomplete way, many of the characteristic phenomena of animal learning. However, even the implied conception of qualitatively distinct learning processes did not long remain unchallenged. Careful observation soon revealed that progressive modification of response occurred in the Pavlovian situation as well as in the problem box. Although in the early stages of conditioning the conditioned and unconditioned responses closely resembled each other, both responses often appeared to undergo marked alteration, and sometimes in different directions. The concept of stimulus substitution clearly could not account for such results. This difficulty was emphasized by the development of many hybrid learning situations which were intermediate between the classical types in that they retained the Pavlov frame while providing the animal with greater opportunities for adaptive modification of response. At the same time the problem box itself was often complicated by the addition of signal properties. So situationally rooted were the earlier conceptions that the blurring of situational distinctions produced a blurring of conceptual distinctions, and the stage was set for the emergence of a theory which would deal with all of the data in terms of a common underlying principle. The possibility that both of the processes highlighted by the classical investigations might operate concurrently under any given set of conditions was not seriously considered. Instead, in accordance with the facile Watsonian formula, all learning was reduced to the formation and strengthening of stimulus-response connections, and although "conditioning" became the preferred designation of the process, something like the Thorndikian conception of effect came to be generally accepted as the connecting principle.

The culmination of this theoretical trend is to be found in the position of Hull (21) who has worked for many years to give it systematic expression. His well-known fourth postulate reduces all learning to the formation and strengthening of stimulus-response connections through the agency of need-reduction. After considering the relation between conditioning and selective learning, Hull suggests "that the differences between the two forms of learning are superficial in nature; *i.e.*, that they do not involve fundamentally different principles or laws, but only differences in the *conditions* under which the (single) principle operates." True, the conditioning experiment may involve the "setting up of a receptor-effector connection *de novo*" (21, p. 78). While "Simple selective learning may involve the mere strengthening of receptor-effector connections already of superthreshold strength before the beginning of the experiment" (21, pp. 77). But in every instance contiguous need-reduction is responsible for the increment in habit strength. Hull points out that the Pavlovian conception cannot account for the selective modification of response in a given stimulus situation, the phenomenon with which the effect principle was designed to deal. He maintains, however, that stimulus substitution ("the setting up of a receptor-effector connection *de novo*") can be regarded as a special case of effect learning if one assumes that the unconditioned stimulus not only elicits the response to be conditioned but constitutes as well a need-reducing "state of affairs." One has only to look for need-reduction (primary or secondary) and it is readily found. In the classical salivation experiment food presented to the animal "reduces" hunger, while in flexion experiments the termination of

shock "reduces" the need established by its onset. Pavlov's "mistaken" emphasis on the *mere occurrence* of the unconditioned stimulus is attributed to the limited nature of the situation that he employed.

Hull's system has proved to be very attractive because of its presumably parsimonious treatment of a wide range of diverse phenomena. One must recognize, however, that the more parsimonious of the two theories is to be preferred only if it can account for available data at least as well as can its competitor. For this reason, as Hilgard and Marquis have pointed out, "there is no logical necessity for reducing all instances of learning to a single explanatory principle" (20, p. 99). Further, one must distinguish between parsimony in verbalization and parsimony in assumption. It may be argued that Hull's need-reduction formula requires a multiplicity of informal supporting assumptions and that it is therefore only apparently parsimonious.

The contemporary tendency to break down the classical distinction between conditioning and selective learning has not been without its critics (10, 20, 23, 31, 34). However, the clearest development of an alternative position—which constitutes an explicit statement of the potentialities present in the earlier dual-process theories—has been provided by Maier and Schneirla (31). On the basis of a careful analysis of representative conditioning experiments, these writers contend that it is necessary to postulate two distinct processes if the data are to be properly understood. The first is a process of *sensory integration* ("sensory-sensory conditioning") in which one stimulus, as a result of contiguous presentation with a second, gradually acquires the functional properties of the second. In addition, there is a process of *selection* in which the organism comes to make those responses which are qualitatively and functionally dependent upon the prevalent motivating conditions. In the first case a relation between afferent processes is established—there is an "extension or qualitative enlargement of the pattern of stimulation which will elicit the critical response" (31, p. 132)—and its essential condition is contiguity of stimulation. In the second case there is a progressive *modification of response* to given stimulating conditions under the influence of reward and punishment.

It should be noted carefully that the two processes are not situationally defined; under certain experimental conditions both must be assumed to occur. For example, Maier and Schneirla account for the development of a conditioned avoidance response in the following terms: In the first phase of the experiment the conditioned stimulus is paired with the shock to the leg and as a result acquires the property of eliciting flexion. Here a previously ineffective stimulus has been transformed into an effective one, and contiguity of effective and ineffective stimuli has been the essential condition. Once the conditioned stimulus becomes capable of eliciting the response, however, selective learning may supervene. The response may now become progressively more specific in a manner which depends upon the conditions under which shock is administered—*e.g.*, the amplitude of flexion may decrease to the minimum necessary to avoid the grill. It should be clear, therefore, that Maier and Schneirla do not deny that selective learning may go on in the conditioning situation, nor do they deny that the unconditioned stimulus—food or shock—may play an important motivational role. They do maintain, however, that the development of stimulus equivalence which is observed in conditioning is the result of a qualitatively

distinct process which depends primarily on contiguous stimulation. It may also be well to point out that Maier and Schneirla did not undertake an explicit analysis of the selection process. Instead they devoted their main efforts to demonstrating the need for a concept of sensory integration and to analyzing the qualitative differences between this process and a selective process in their consequences for learning.

Is there then a process of afferent modification which is brought about by contiguity of stimulation and which can occur independently of need-reduction? Replying from the point of view of Hull's theory, Kendler and Underwood (25) have recently attempted to demonstrate that the need-reduction principle is adequate to account for all the phenomena of learning, and consequently that the concept of sensory integration in conditioning is superfluous. Unfortunately, however, the Kendler and Underwood paper serves to confuse rather than to clarify the issues. It is our opinion that there is a substantial body of evidence which these writers, like Hull, either entirely ignore or treat in a superficial and misleading manner, and that these data clearly indicate the existence of a process of sensory integration.

SENSORY INTEGRATION IN CONDITIONING

Evidence in support of our position may be marshalled under three main headings. First, an examination of the phenomena of stimulus-substitution reveals that attributing need-reducing properties to the unconditioned stimulus does not fully account for the behavioral events in conditioning. Second, the investigations of sensory preconditioning present positive support for the contiguity principle. Finally, researches on the nature of the neural mechanisms involved in conditioning have crucial implications for the differentiation of sensory integration from response modification. Each of these lines of inquiry will be explored in turn.

1. *The unconditioned stimulus as reinforcing agent.* To account for any instance of conditioning in terms of Hull's theory, one must be able to demonstrate (a) the contiguous occurrence of the conditioned stimulus and the response which it is to elicit, and (b) need-reduction, either primary or secondary, which follows closely upon the stimulus-response conjunction in question. Most conditioning situations, although not all, provide the temporal contiguity of conditioned stimulus and response, but it is usually much more difficult to find an explicit instance of need-reduction. The problem has customarily been resolved by attributing two functions to the unconditioned stimulus—response-production and need-reduction. Thus, in accounting for an instance of salivary conditioning in which food is used as the unconditioned stimulus, Hull assumes that the food plays a double role. It not only serves to elicit the response to be conditioned, but by acting upon the hunger drive serves to provide the essential factor of need-reduction as well.

On the surface this interpretation seems to be fairly straightforward. However, one soon finds that Hull is not quite sure of how food may actually function to "reduce the hunger need" either in this or in any other learning situation. At one point Hull arrives at the conclusion that the delay between the ingestion of food and its absorption "makes it distinctly improbable" that the ingestion of food provides direct need-reduction, and calls the principle of secondary reinforcement to his aid. But since a stimulus only acquires the property of secondary reinforcement as a result of having

been "closely and consistently associated with need diminution" it becomes necessary to introduce a further set of assumptions to bridge the temporal gap between ingestion and absorption. To this end Hull postulates a complex chain of backwardly-directed stimulus-response connections which finally result in the establishment of a connection between food and a hypothetical "fractional goal response." It becomes unnecessary to make such an elaborate set of inferences if stimulus-substitution is accounted for in terms of sensory integration rather than need-reduction. The theory of sensory integration will also take care of all the data subsumed under the heading of secondary reinforcement, *i.e.*, indications that stimuli contiguously related to goal objects may under certain conditions acquire goal properties. But we need not rely on postulate-counting to provide a solution to the problem. There is abundant evidence with which the need-reduction principle, parsimonious or not, is entirely unable to deal.

When salivary conditioning is established with acid instead of with food, it is no longer possible to regard the unconditioned stimulus as a need-reducer. However, it is possible in this case to maintain that need-reduction occurs as a result of the dilution of acid by the flow of saliva. Unfortunately for this interpretation, Finch (13) has demonstrated that salivary conditioning occurs with acid even when the flow of saliva is inhibited during the training series by the injection of atropine. How then is the need aroused by the acid reduced promptly enough to establish a connection between the conditioned stimulus and a salivary response?

When we turn to experiments with shock, with which Hull has dealt most directly, the inadequacy of his position becomes even more apparent. Seeking for need-reduction in these experiments, Hull arrives at the conclusion (supported by Kendler and Underwood) that the shock creates a need which is reduced when the shock terminates. Buzzer and shock to the leg are paired, and the shock produces both leg flexion and a state of need. Then the shock terminates, the need is reduced, and the buzzer-flexion connection is thus established in accordance with Postulate IV. Hull does not distinguish between avoidance situations and those in which the conditioned stimulus is always followed by brief shock whether or not the conditioned response intervenes. Since the reinforcing state of affairs in learning is not necessarily the physical consequence of the act which is reinforced, as Hull tells us (21, pp. 80–81), it apparently does not matter whether the conditioned response terminates the shock or whether the shock *merely terminates*. Shock creates a need which its termination reduces, and any stimulus response conjunction which happens to be in the temporal vicinity of these events is strengthened as a consequence.

As Hilgard has clearly recognized, Hull's conception of the role of shock may account for the selection of *escape* responses, but it cannot deal with the successful development of *avoidance* responses. He writes:

"If an animal runs down an alley, meets a charged grid, and leaps ahead from it to safety, the leap is associated with need-reduction (pain-alleviation) so that, by strict reinforcement theory, the next time the animal should do what it last did, only perhaps more intensely. It should run down the alley faster, touch the grid and make a jump to safety. . . . Rats do not do this. They slow up in the alley and try not to approach the grid. That is the difference between avoidance and escape behavior" (19, p. 108).

Evidently one can only account for avoidance if one assumes that stimuli contiguously related to the *onset* of shock acquire the functional properties of shock.

When we turn to the data of some representative conditioning studies, we find clear evidence of the inadequacy of Hull's interpretation of the function of shock. First let us consider the experiment by Brogden on the effectiveness of substitute rewards. Brogden (2) found that a conditioned avoidance response, established with the use of shock, could be maintained at a high level by substituting food for shock. Food was given whenever the conditioned response was made and withheld when the response failed to appear. These results establish the fact that shock may play a motivational role in the maintainence of an established conditioned response, and that the hunger motive may effectively replace the shock motive. It should be noted, however, that in this experiment the *absence* of shock rather than the *onset and termination* of shock functioned as the motivational equivalent of food.

Once the feasibility of reward substitution has been established, it becomes possible to evaluate the results of an experiment by Brogden, Lipman, and Culler (7). These investigators studied the rate at which an avoidance response to a tone of 1000 cycles extinguished under two different conditions. In procedure A, reaction to the conditioned stimulus was followed by thoracic shock instead of by the leg shock which had served as the unconditioned stimulus in the original training. In procedure B, the tone was never reinforced in any way; shock was entirely eliminated. A strict application of Hull's interpretation of the role of shock leads to the prediction that extinction should occur more rapidly under condition B, since the termination of thoracic shock which closely follows each tone-flexion conjunction in condition A should constitute a reinforcing state of affairs and thus tend to maintain the response. In fact, Hull's conception requires us to predict that no extinction should occur at all under condition A, since the termination of thoracic shock should provide as much need-reduction, *per se,* as does termination of leg-shock. But these predictions are not at all borne out by the experimental results. Extinction occurred under both conditions, and considerably more rapidly under condition A. Thoracic shock accelerated rather than retarded the extinction process. Certainly shock has been demonstrated to have motivational significance in this experiment, but it functions in the reverse of the manner which Hull describes.

Another experiment by Brogden (4) indicates that once a conditioned avoidance response has been established it *can* be maintained following a shift in the locus to which the unconditioned stimulus is applied, but *only* when the shock is administered for *failure* to make the conditioned response. Under these circumstances the conditioned response is *never* reinforced in Hull's sense of the term; that is, the conditioned response is never followed by shock and shock-termination, while failure to respond is *always* followed by shock and shock-termination. If Hull's interpretation of the role of shock were correct, therefore, we should expect that the conditioned response would soon disappear.

But Brogden's experiment (4) goes even further. It demonstrates that an extinguished avoidance response can be *reestablished* when shock to a new locus is administered for failure to respond. Brogden conditioned four animals to a bell, using shock to the *left* forepaw as the unconditioned stimulus. As soon

as an avoidance response was established, shock was entirely eliminated and the response extinguished. Now the bell was reintroduced, and followed by shock to the *right* forelimb when the animals failed to respond. The shock produced flexion of the right forelimb, but in a few trials the animals began to respond to the conditioned stimulus with flexion of the left forelimb and this response was maintained at a high level. The conditional response reappeared so quickly in this experiment that there was no opportunity for a new sensory integration—bell-shock to right forelimb—to be established. Further work by Brogden indicates, however, that when the conditions were changed in such a way as to require a greater number of contiguous presentations of bell and shock to the right forelimb, a new integration was established and "ambiguous" conditioning resulted.

All of these studies point clearly to the inadequacy of Hull's interpretation of the role of shock in flexion conditioning. A brief shock contiguous with a stimulus-response conjunction does not in itself establish a tendency for the stimulus to elicit the response. And if the Hullian interpretation is rejected, there is no alternative but to postulate a process of sensory integration to account for stimulus substitution. Guthrie's (18) version of the contiguity principle is not an acceptable alternative because the phenomenon of extinction demonstrates that mere contiguity of *stimulus and response* has no reinforcing value.

Before we proceed to the sensory preconditioning studies, it is necessary to deal with another experiment which has been discussed both by Maier and Schneirla and by Kendler and Underwood, and which bears on Hull's conception of the role of shock. Brogden, Lipman, and Culler (7) trained eight guinea pigs to run in a modified activity wheel. A 1000 cycle tone served as the conditioned stimulus and shock as the unconditioned stimulus. For four of the animals, the tone was always followed by brief shock irrespective of the kind of response which appeared. For the other four, running terminated the shock and running to the tone entirely prevented the occurrence of shock. The effect of the two procedures on the incidence of running to the tone was measured.

Unfortunately Brogden, Lipman, and Culler present no data on the initial responses of the animals to the shock. However, one may assume without much danger of error that the initial incidence of running was the same for both groups. Since running to shock was followed in both groups by shock-termination (in one group running terminates the shock while in the other group shock terminates automatically after a brief interval), an equal initial tone-run connection should have been established in each group. If Hull's view is correct once the conditioned running has made its appearance, the performance of the two groups should diverge. In the avoidance group, running to the tone is *never* followed by shock-onset—which means that this behavior is never followed by shock-termination—and consequently is never "reinforced." For the non-avoidance group, on the other hand, the conditioned running response is always followed by brief shock, and consequently by the need-reducing properties of shock-termination. Under these circumstances Hull's theory leads to the prediction that the conditioned running response in the avoidance group should be a relatively weak and unstable affair. Each time the response occurs a process of extinction should automatically ensue. What Brogden, Lipman, and Culler found, however, was that

running rapidly came to be the exclusive mode of response to the tone in the avoidance group. Within an average 200 trials the avoidance animals achieved a perfect score and ran consistently to the tone. On the other hand, despite the fact that running was always followed by shock-termination for the non-avoidance group the incidence of running remained low. For the most part these animals "literally 'sat tight,' held the breath, and tensely awaited the shock" (7, p. 111).

In order to account for these results, Maier and Schneirla (31) find it necessary to propose a two-fold process. In both groups of animals there occurred a process of sensory integration in which the tone, as a result of its contiguous relation to the shock, acquired the functional properties of shock. In addition, there occurred a process of selective modification of response. We do not have full information on the course of response modification in the non-avoidance group, but we are told that the crouching pattern became the predominant response of these animals to the tone-shock combination, perhaps became crouching to some extent diminished the effectiveness of the shock. Nevertheless, the course of selective learning in the avoidance group is clear. The running pattern rapidly became the principal mode of response to the tone *because* it was never followed by shock.[1]

[1] In a recent repetition of this experiment, Sheffield (35) found, as one might expect, that certain signs of extinction *did* appear following a number of successful avoidance responses. "As training continued, however, more and more successive conditioned responses occurred without requiring reinforcement" (p. 171). Sheffield's avoidance animals, unlike those of Brogden, Lipman, and Culler, did not reach the 100 per cent level probably, as he suggests, because they had previously been given many trials of non-avoidance training.

In dealing with this position Kendler and Underwood imply that stimulus substitution and selective learning must be assumed to occur successively in time. However, this assumption is not essential to the theory. Once it is realized, however, that temporal sequence is not a crucial problem, the whole point of the Kendler-Underwood argument disappears. The development of stimulus equivalence and the modification of response are not to be regarded as temporal phases. These two *kinds* of learning represent qualitatively different processes which may occur successively or concurrently, dependently or independently of each other. In the study by Brogden, Lipman and Culler, therefore, two kinds of learning are occurring in both groups of guinea pigs. One kind of learning involves stimulus substitution—the tone becomes the equivalent of the shock. The other kind of learning is selective learning—the response to the unconditioned stimulus (or, after effective equivalence is established, to the conditioned stimulus) is modified to adapt the animal to the motivational requirements of the situation. Both groups of animals may have common associative learning. However, the nature of response modification differs for the two groups. Since the consequences which are attendant upon the responses are different, the animals fixate those contrasting patterns of response which have adaptive value. Considered in this light, contiguity learning and selective learning are occurring simultaneously, with contiguity determining the development of stimulus equivalence and selective learning determining the organization of the response pattern. From this point of view, the variations of this experiment proposed by Kendler and Underwood to test the two-process theory have no relevance whatsoever.

In dealing with the criticisms ad-

vanced by Kendler and Underwood it is also necessary to consider the results of an experiment by Girden (14) which they believe to contradict the position of Maier and Schneirla. Girden presented shock to the foreleg of the dog for varying numbers of trials prior to presenting the stimulus to be conditioned. The nature of the conditioned response obtained depended on the stage of response modification which had been developed in the course of experience with the unconditioned stimulus. As Girden reports: "If the unconditioned response was still at the reflexive stage, then the conditioned response assumed the same form. If, however, sufficient preliminary training with the unconditioned stimulus had been first given, then the voluntary conditioned response appeared in short order" (14, p. 679). These results are directly relevant to the conception of qualitatively distinct processes—stimulus substitution and selective learning—operating in the conditioning situation. The experiment simply reveals that a certain amount of selective learning may occur prior to the process of stimulus substitution.

2. *Sensory preconditioning.* More than twenty years ago, Prokofiev and Zeliony (33) performed the first of a series of experiments which provide strong support for the contiguity principle. These investigators presented their human subjects with the sound of a metronome for 10 seconds and immediately after applied rhythmic pressure to the forearm. This procedure was continued for several days, 5 to 10 times each day. Next the tactile stimulus was paired with an electric shock to the hand until conditioned arm withdrawal was established. When the metronome was subsequently presented alone, it was successful in eliciting arm withdrawal in two of the three subjects. As it stands, this study, although suggestive, does not permit of unambiguous interpretation, because of the small number of subjects and the failure to control possible generalization from auditory to rhythmic tactual stimulation.

Shipley (36) continued the investigation of the problem by using a larger group of subjects and conditioning the eye wink evoked by a sudden tap on the cheek to the weak flash of an electric light. After conditioning had been established, the tap on the cheek was paired with shock to the finger until conditioned finger withdrawal occurred. Now, upon presentation of the light flash alone, nine of the fifteen subjects responded by finger-withdrawal, a response which had never before occurred in conjunction with the light stimulus. In a control group of 10 subjects, tap on the cheek was given alone and then paired with shock to the finger until a conditioned withdrawal was established. A light flash presented to these subjects produced no instance of finger withdrawal, demonstrating that the behavior of the experimental subjects was not the result of stimulus generalization.

Maier and Schneirla believe that Shipley's results are consistent with a sensory integration theory. In the first stage of Shipley's experiment, the light flash becomes equivalent to strike and in the second stage strike becomes equivalent to shock. Presentation of light therefore results in finger-withdrawal. Hull does not deal with the same experiment as do Maier and Schneirla, but with another study by Shipley (37). However, his discussion may be extrapolated to provide an explanation for the experiment which Maier and Schneirla discuss. Hull interprets the finger retraction to light as the result of indirect generalization. Such generalization occurs because the light evokes the wink; the wink produces a proprioceptive stimulation; and

since the proprioceptive stimulation was conditioned to finger retraction in the second phase of Shipley's procedure, it later evokes the withdrawal response.[2] Therefore, the new effectiveness of the light is dependent upon the occurrence of the wink. Fortunately, there is some experimental evidence which bears on the role of the wink-aroused proprioceptive stimuli upon which Hull calls to account for Shipley's results. Lumsdaine's (30) photographs show that on some occasions finger withdrawal occurs prior to the wink or even in the absence of the wink. However, Hull refuses to be tied to any explicit behavior and vaguely speaks of "numerous other reactions conditioned at the same time as the wink" (21, p. 193). This vagueness makes his hypothesis entirely untestable and should lead to its immediate rejection on the basis of the criteria which he himself sets forth.

Several recent investigations of the phenomenon of sensory preconditioning avoid the weakness of earlier work by using stimuli in the early presentations which can only with difficulty be considered to have need-reducing properties. In an experiment conducted with dogs, Brogden (3) subjected one group of animals (experimental group) to 200 simultaneous paired presentations of a bell and a light. A second group of animals (control group) received no such paired stimulation. Subsequently, both the control and experimental animals were trained to make a forelimb flexion response to one of the stimuli. In the case of the experimental animals it was found that when forelimb flexion had been established to one of the stimuli (either light or bell) the presentation of the other stimulus also tended to evoke the flexion response. That this behavior was not simply the result of stimulus generalization is shown by the fact that the control group, which had not experienced the contiguous presentation of the two stimuli earlier, did not respond with forelimb flexion to the stimulus to which the flexion had not been explicitly conditioned.

Brogden further explored the phenomenon of sensory pre-conditioning in two studies at the human level. One of these studies was unsuccessful in demonstrating the phenomenon because of an unfortunate choice of experimental procedure (5). The second experiment (6) shows sensory pre-conditioning at the human level quite clearly. In this study one experimental and several control groups were used. The subjects comprising the experimental group were first placed in a room and observed through a one-way window. When the subjects' gaze happened to be directed toward the stimulus cabinet, a light and a complex tone were simultaneously presented. When a total of 10 such paired stimulus presentations had occurred, the subjects were given instructions leading to the formation of a key-pressing response to light. They were then presented with a sequence of 10 light, 10 tone, and 10 light stimuli. The subjects of one control group (sensory-generalization control) received the same testing but no initial paired presentation of light and sound. Another control group received the same test, but prior stimulation with tone alone. The number of responses to tone (although the subjects had only been instructed to respond to light) was significantly greatest for the experimental group, while no significant

[2] Hull must assume an intermediate response, the wink to the light flash, as the basis for the *new* effectiveness of the light flash. In this interpretation he must also assume that two backward conditionings occur and that strike termination has a need-reducing function. Here we have a plethora of unsupported hypotheses in a presumably parsimonious theory.

differences appeared among the control groups.

A study by Karn (22) on conditioned finger-withdrawal corroborates Brogden's findings. Prior to establishing the finger-withdrawal pattern, Karn stimulated his experimental group (12 subjects) 50 times with simultaneously presented light and sound. The control group (12 subjects) did not have this experience. After a buzzer-shock avoidance response had been established to the criterion of five successive anticipatory finger withdrawals, both groups were stimulated with ten presentations of light alone. The experimental group made 75 withdrawals out of 120 possible responses, whereas the control group made only nine withdrawals out of a possible 120 responses. Further, only two of the experimental subjects failed to respond to light, while eight of the control subjects failed to do so. Karn attributes this difference in behavior "to an association formed between visual and auditory stimuli during the preliminary pre-conditioning period" (22, p. 544).

Sensory pre-conditioning has also been demonstrated at the level of the rat. In an unpublished Cornell experiment, rats were placed in a box, the floor of which was covered by a grid. In the first stage of the experiment light was paired with brief shock from the grid. As soon as the animals showed signs of being excited by the light itself, continuous shock was introduced and the animals learned to escape through a door which had previously been locked. In the third phase of the experiment, light alone elicited the escape response. Stimuli not previously paired with shock did not produce this response.

The results of the sensory pre-conditioning experiments require us to postulate a process of afferent modification (sensory integration), the essential condition for which is contiguity of stimulation, and which takes place independently of need reduction. In the Brogden and Karn studies paired presentation of bell and light establishes a functional relation between them which is demonstrated by the fact that when one of the pair becomes the effective stimulus for a new response the other also becomes capable of eliciting the response. It would be too far-fetched to contend that the bell-light combination constitutes a reinforcing "state of affairs." It might be contended that the termination of shock in the first stage of the Cornell experiment provided the requisite need-reduction, although we have already demonstrated the inadequacy of this conception. Even if this assumption is made, the fact that the light subsequently elicited the directed escape response with which it had never before been in conjunction cannot be explained. Only a concept of sensory integration can deal adequately with these results.

3. *The experimental delimitation of neural structures involved in conditioning.* In defending Hull's need-reduction principle, Kendler and Underwood have maintained that they are not concerned with evidence bearing upon the operation of any specific type of neural mechanism in learning. The theory, they contend, is a "non-reductive" one and has no relation to physiological processes once "language trends" have been "discounted." This assertion is patently contrary to fact. Anyone who has read Hull knows that he makes use of supporting physiological data. But irrespective of Hull's practice, the present writers hold that since the material substratum for learning is the nervous system, a fruitful theory is one that yields inferences of a neurological kind, which in turn yield testable hypotheses crucial for the theory. A non-reductive

approach indicates theoretical weakness rather than theoretical strength.

As we have already indicated, Maier and Schneirla are not content merely to defend the principle of stimulus substitution by contiguity. In order to explain the observed relationships, they advance a conception of sensory integration which is the beginning of a neurophysiological theory. This conception, preliminary as it is, fits the results of a variety of experiments in which attempts have been made to delimit the neural structures involved in conditioning.

Loucks (29) found that when a buzzer was paired with a shock stimulus which was applied directly to the motor cortex and thus elicited leg flexion, no conditioning could be established. However, when the animal was given food each time leg flexion occurred, the buzzer soon began to elicit the flexion response. In the first part of the experiment, say Maier and Schneirla, neither sensory integration nor selective learning could occur. There could be no sensory integration because there was no contiguity of afferent processes, and there could be no selective learning because the flexion response was not rewarded. In the second phase of the experiment, the food reward made selective learning possible. Kendler and Underwood disagree with the interpretation in so far as the first phase of the experiment is concerned. They reject the conception of sensory integration and maintain that the absence of effective sensory relationships was unimportant. Learning failed to occur, they assert, because the response was not followed by need diminution. But what need diminution follows the flexion response when it is aroused, not by cortical shock, but via the afferent pathways of the leg? To answer this question, Kendler and Underwood must attribute need-reducing properties to shock termination, a conception which we have already shown to be inadequate.

Another experiment which bears on this problem is that of Kleitman (26) who attempted to establish conditioned salivation in dogs when the salivary response was produced by pilocarpine, an agent which acts directly to arouse the salivary gland. At no time was conditioned salivation established by such a procedure although the conditioned stimulus was paired with the unconditioned response in hundreds of training trials. However, conditioned salivation could easily be established if the agent which caused the increased activity of the salivary gland was morphine, which acts indirectly through the central nervous system. Finch (12) working some ten years later confirmed Kleitman's findings. Why were the results with morphine different from those obtained with pilocarpine? The concept of sensory integration suggests that it was because the morphine provided effective sensory relations which pilocarpine did not. The Hullian can only assume, *ad hoc*, that the morphine must have provided some sort of need-reduction while the pilocarpine did not.

The concept of sensory integration leads Maier and Schneirla to the prediction that conditioning can take place even when the response to the unconditioned stimulus is prevented from occurring, and the results of a variety of experiments are consonant with this view. Light and Gantt (28), working with dogs, crushed the motor pathways to the right hind leg, thus producing a temporary but total motor paralysis of this limb. During the period of total paralysis the investigators repeatedly paired a buzzer with electric shock to the paralyzed limb. At no time during this training period did the limb exhibit flexion, although other general movements of the body occurred. Af-

ter training, the motor pathways were allowed to regenerate, and tests for conditioning were made. In these tests the buzzer elicited the flexion response which had never before appeared.[8] Crisler (9) and Finch (13) have reported similar results with salivary conditioning. Although during training the glandular response was inhibited by atropine, the conditioned response was manifested after the withdrawal of the inhibitory agent.

In order to deal with results of this sort, Kendler and Underwood find it necessary to abandon their "non-reductive" approach and make hypotheses about physiological processes in the animal. In discussing the Light and Gantt experiment they write:

[8] These findings were confirmed in a repetition of the experiment by Kellogg, Scott, Davis and Wolf (24), although they offer a somewhat different interpretation. They conclude that "the conditioned flexion response is really a general reaction involving postural and other bodily changes. To eliminate one segment of the response does not eliminate conditioning. When not prevented from doing so, the segment fits readily into the whole of which it is a natural part" (p. 72). We are also told, however, that "the paralyzed subjects . . . (by swaying, swinging, or stretching) . . . were actually accomplishing the result of lifting the foot, but without the use of the flexing muscles, during their training. With the return of function in the previously paralyzed members, they substituted the direct for the indirect method of accomplishing the same result" (p. 73). Evidently the general pattern which appeared after recovery was not the pattern elicited by the unconditioned stimulus during the training trials.

Recently Girden (15) has presented new evidence in support of a motor theory of conditioning. The evidence which he presents is unconvincing, however, since it is based on work with erythrodine, a curare-like substance which he himself has demonstrated to have widespread cortical effects that are not very well understood at the present time. Girden's argument rests on the assumption that the two drug states employed in his experiments are "continuous" for skeletal processes because they appear to be continuous for visceral processes.

"A reinforcement theory does not demand, of course, that the response per se has to occur for reinforcement to occur. Since the cessation of the shock produces a reinforcing state of affairs, a functional relation can be established between the conditioned stimulus and the potential overt response (efferent discharge). Light and Gantt point out that it is reasonable to assume that the efferent discharge for foot withdrawal was made regardless of the fact that it did not produce the response while the nerve was crushed" (25, p. 214).

The quotation also shows clearly that the Kendler-Underwood interpretation stands or falls with the conception that termination of shock in itself constitutes a reinforcing state of affairs. Since the inadequacy of this conception has already been demonstrated, it seems necessary to postulate a process of sensory integration in order to account for the data in question.

Maier and Schneirla also suggest that the results obtained in work with decorticate dogs (11, 16) lend support to the distinction between conditioning (sensory integration) and selective learning. In these experiments shock to the limb was employed as the unconditioned stimulus and a "diffuse" or "massive" type of conditioned response readily appeared. A comparison of the performance of decorticate and intact animals in the same situation revealed that while in the intact specimen the initial diffuse response to the conditioned stimulus is modified and converted into a precise response, the decorticate animal is limited to the initial diffuse reaction. According to Maier and Schneirla, "this seems to mean that association by contiguity is more primitive than selective learning, since it can proceed in the absence of cerebral cortex although selective learning is then excluded. . . . The postulation of two qualitatively different learning mechanisms makes understandable the fact

that the first stage in conditioning can occur unimpaired although the second is excluded in spinal and decorticate animals" (31, p. 122). Kendler and Underwood suggest, on the other hand, that the results in question can be accounted for on the assumption that the decorticate dog is "incapable of developing" an organized response to the shock. But this is merely a restatement of the problem. Why is the decorticate dog incapable of developing an organized response to shock? If stimulus substitution and selective learning are not distinct processes, why is one possible and not the other? Certainly, as Bromiley (8) has demonstrated, the decorticate dog is capable of specific response to shock, and when the shock is such as to elicit a specific response, the conditioned stimulus with which it is paired elicits the same response. Apparently it is selective modification of response which cannot occur in the decorticate animal.[4]

SENSORY INTEGRATION AS A GENERAL PROCESS OF LEARNING

Thus far we have attempted to demonstrate that the development of stimulus equivalence in conditioning experiments requires us to postulate a process of sensory integration—a process of afferent modification which depends primarily upon contiguity of stimulation and which can occur in the absence of need-reduction. We may now ask whether the applicability of this conception is limited to the kind of data with which it was derived to deal, or whether its usefulness is not considerably greater. Although the process of sensory integration is most clearly revealed in conditioning, we believe that it will also make it possible to explain many of the phenomena which occur in a variety of other learning situations. We do not think that all phases of maze, discrimination, or problem-box learning can be reduced to a process of afferent modification, but once we are able to determine those aspects of learning which can, and those which cannot, be accounted for in terms of sensory integration, we will be in a better position to postulate complementary processes.

In the previous section we have spoken of sensory integration as though it occurs only as a result of the contiguous presentation of exteroceptive stimuli, under the full control of the experimenter. It is now possible to introduce a broader conception of the conditions under which the process occurs. Consider, for example, the case of a hungry rat which approaches the positive card in a discrimination situation and finds food behind it. On the next trial the animal will be more likely to approach the positive card, but it is not necessary to conclude that a direct functional relation (or connection) between the card and the adient response has been established. Thinking in terms of sensory integration, we may say that the positive card has acquired some of the functional properties of the food with which it has been in contiguous relation, so that adient responses formerly elicited by the food alone will now be elicited by the card.

Much of the same sort of explana-

[4] Moreover, the conditioned responses developed by the operated animal often seem to have need-increasing, rather than need-reducing consequences. For example, when the animal in the experiment of Girden *et al.* (16) was about three-quarters decorticated, its response to the shock to the foreleg consisted of bilateral foreleg extension, a response which placed the feet more firmly against the grill and thus intensified the direct effectiveness of the shock. This response was readily conditioned to the auditory stimulus. The writers say that "the new conditioned response was obviously a perfect case of diffuse behavior which is decidedly non-adaptive; since at every trial the dog, by planting the forefeet on the grids, received the full shock instead of escaping it" (p. 372).

tion may be suggested for the elimination of blind alleys in the maze. In preliminary trials, it may be assumed, a cul entrance acquires the functional properties of the cul's end by a process of sensory integration which, depending on the length and complexity of the blind alley, may occur directly or in stepwise fashion. This conception of progressive afferent integration is consonant with the facts of mammalian neural organization and provides a process-oriented approach to phenomena with which the cognitive theorists (27, 40) have been able to deal only in dangerously anthropomorphic terms, and with which Hull has been entirely unable to deal. The fact that sensory integration may proceed in the absence of need and need-reduction suggests an explanation of "latent learning" which does not require us to assume that the rat can function at the intellectual level of man. At the present time we know very little about the conditions under which sensory integration occurs, although it is probable that the powerful afferent consequences of drive states which exist at any given moment may play a significant role in the process. The concept of sensory integration is not so much a solution of problems as it is a starting point for a whole series of new investigations designed to explore the process of perceptual organization at different developmental levels.

The concept of sensory integration may even enable us to deal with some aspects of modification of behavior in the problem box, which has long been dominated by the effect principle. In the Skinner box, for example, the rat experiences food only in the vicinity of the lever. As the lever and other local stimuli acquire food-properties, the animal orients to these stimuli and the only responses which appear are those which they elicit. The critical features of the stimulus situation may in this way be differentiated out of the mass, and the range of behavior accordingly restricted.

It is unlikely, however, that response modification can be fully accounted for in afferent terms. Many of these changes in behavior apparently require the direct reorganization of afferent-efferent relationships. Since there is no reason to believe that proprioceptive stimuli cannot participate in the integration process, we may assume that the specific proprioceptive consequences of the correct response may also come to acquire food properties (17). But how this afferent modification results in the dominance of the correct response is another question. The problem posed by results such as those of Loucks (29) illustrates the limited applicability of the sensory integration concept. Loucks paired a buzzer with shock to the motor cortex of the dog. The shock produced flexion, and if the flexion was followed by food, the buzzer alone soon began to elicit the response. The buzzer may have been integrated with flexion afferents and with food afferents, or with both, but since neither of these components evokes flexion, the integration does not explain why the buzzer acquired that property.

The cognitive theorists do not face this problem. How "knowledge of means-end-relations" is translated into appropriate behavior—how afferent integrations are translated into appropriate efferent patterns—we are not told. Nevertheless, the establishment and alteration of functional relations between afferent and efferent processes present a theoretical problem which must sooner or later be solved. Effect theory represents an attempt to define the conditions under which changes of this kind take place, but it gives no hint of the underlying mechanisms.

SUMMARY

The classical investigations of Pavlov and Thorndike suggest the operation of two qualitatively distinct learning processes. The conditioning situation directs attention to the development of stimulus equivalence (stimulus substitution—a process of afferent modification (sensory integration) which results from contiguity of stimulation and which may occur in the absence of need-reduction. The problem box emphasizes the selective modification of response in accordance with motivational requirements.

The contemporary tendency to break down the distinction between these processes, as it is exemplified in the system of Hull, is here evaluated. Hull and his adherents have attempted to reduce all learning to the establishment and strengthening of stimulus-response connections under the influence of need-reduction. The stimulus substitution which occurs in conditioning experiments can be accounted for in these terms only if it is possible to demonstrate that the process depends upon (a) the close conjunction of the conditioned stimulus and the response which it is to elicit and (b) contiguous need-reduction. Our analysis of the evidence reveals that stimulus equivalence develops even when neither of these conditions is met. We conclude, therefore, that at least *two* processes of learning—sensory integration and selective modification of response—must be postulated if the data of conditioning experiments are properly to be understood. Neither of these processes is unique to conditioning, but both may operate in a variety of learning situations.

BIBLIOGRAPHY

1. BIRCH, H. G. The relation of previous experience to insightful problem-solving. *J. comp. Psychol.*, 1945, **38**, 367–383.
2. BROGDEN, W. J. Unconditioned stimulus-substitution in the conditioning process. *Amer. J. Psychol.*, 1939, **52**, 46–55.
3. ——. Sensory pre-conditioning. *J. exp. Psychol.*, 1939, **25**, 323–332.
4. ——. Conditioned flexion responses in dogs re-established and maintained with change of locus in the application of the unconditioned stimulus. *J. exp. Psychol.*, 1940, **27**, 583–600.
5. ——. Test of sensory pre-conditioning with human subjects. *J. exp. Psychol.*, 1942, **31**, 505–517.
6. ——. Sensory pre-conditioning with human subjects. *J. exp. Psychol.*, 1947, **37**, 527–539.
7. ——, LIPMAN, E. A., & CULLER, E. The role of incentive in conditioning and extinction. *Amer. J. Psychol.*, 1938, **51**, 109–117.
8. BROMILEY, R. B. Conditioned responses in a dog after removal of neocortex. *J. comp. physiol. Psychol.*, 1948, **41**, 102–110.
9. CRISLER, G. Salivation is unnecessary for establishment of the salivary conditioned reflex induced by morphine. *Amer. J. Physiol.*, 1930, **94**, 553–556.
10. CULLER, E. Recent advances in some concepts of conditioning. PSYCHOL. REV., 1938, **45**, 134–153.
11. ——, & METTLER, F. A. Conditioned behavior in the decorticate dog. *J. comp. Psychol.*, 1934, **18**, 291–303.
12. FINCH, G. Pilocarpine conditioning. *Amer. J. Physiol.*, 1938a, **123**, 378–382.
13. ——. Salivary conditioning in atropinized dogs. *Amer. J. Physiol.*, 1938b, **124**, 136–141.
14. GIRDEN, E. Conditioning and problem-solving behavior. *Amer. J. Psychol.*, 1938, **51**, 677–688.
15. ——. Role of the response mechanism in learning and in "excited emotion." *Amer. J. Psychol.*, 1943, **56**, 1–20.
16. ——, METTLER, F. A., FINCH, G., & CULLER, E. Conditioned responses in a decorticate dog to acoustic, thermal, and tactile stimulation. *J. comp. Psychol.*, 1936, 21, 367–385.
17. GRICE, G. R. The relation of secondary reinforcement to delayed reward in visual discrimination learning. *J. exp. Psychol.*, 1948, **38**, 1–16.
18. GUTHRIE, E. R. *The psychology of learning.* New York: Harper, 1935.
19. HILGARD, E. R. *Theories of learning.* New York: Appleton-Century-Crofts, 1948.

20. ——, & MARQUIS, D. G. *Conditioning and learning.* New York: Appleton-Century, 1940.
21. HULL, C. L. *Principles of behavior.* New York: Appleton-Century, 1943.
22. KARN, H. W. Sensory pre-conditioning and incidental learning in human subjects. *J. exp. Psychol.,* 1947, **37**, 540–544.
23. KELLOGG, W. N. An eclectic view of some theories of learning. PSYCHOL. REV., 1938, **45**, 165–184.
24. ——, SCOTT, V. B., DAVIS, R. C., & WOLF, I. S. Is movement necessary for conditioning? *J. comp. Psychol.,* 1940, **29**, 43–47.
25. KENDLER, H. H., & UNDERWOOD, B. J. The role of reward in conditioning theory. PSYCHOL. REV., 1948, **55**, 209–215.
26. KLEITMAN, N. The influence of starvation on the rate of secretion of saliva elicited by pilocarpine, and its bearing on conditioned salivation. *Amer. J. Physiol.,* 1927, **82**, 686–692.
27. KRECHEVSKY, I. "Hypotheses" in rats. PSYCHOL. REV., 1932, **39**, 516–532.
28. LIGHT, J. S., & GANTT, W. H. Essential part of reflex arc for establishment of conditioned reflex. Formation of conditioned reflex after exclusion of motor peripheral end. *J. comp. Psychol.,* 1936, **21**, 19–36.
29. LOUCKS, R. B. The experimental delimitation of structures essential for learning: The attempt to condition striped muscle responses with faradization of the sigmoid gyrus. *J. Psychol.,* 1935, **1**, 5–44.
30. LUMSDAINE, A. A. (*cf.* HILGARD & MARQUIS, p. 230 *et seq.*) Conditioned eyelid responses as mediating generalized conditioned finger reactions. *Psychol. Bull.,* 1939, **36**, 650.
31. MAIER, N. R. F., & SCHNEIRLA, T. C. Mechanisms in conditioning. PSYCHOL. REV., 1942, **49**, 117–134.
32. PAVLOV, I. P. *Conditioned reflexes.* London: Oxford Univ. Press, 1927.
33. PROKOFIEV, G., & ZELIONY, G. Des modes d'associations cerebrales chez l'homme et chez les animaux. *J. de Psychol.,* 1926, **23**, 1020–1028.
34. SCHLOSBERG, H. The relationship between success and the laws of conditioning. PSYCHOL. REV., 1937, **44**, 379–394.
35. SHEFFIELD, F. D. Avoidance training and the contiguity principle. *J. comp. physiol. Psychol.,* 1948, **41**, 165–177.
36. SHIPLEY, W. C. An apparent transfer of conditioning. *J. gen. Psychol.,* 1933, **8**, 382–391.
37. ——. Indirect conditioning. *J. gen. Psychol.,* 1935, **12**, 337–357.
38. SKINNER, B. F. *The behavior of organisms.* New York: Appleton-Century, 1938.
39. THORNDIKE, E. L. *Animal intelligence.* New York: Macmillan, 1911.
40. TOLMAN, E. C. *Purposive behavior in animals and men.* New York: Appleton-Century, 1932.

[MS. received March 28, 1949]

Errata

In C. J. Burke's article "A Theory Relating Momentary Effective Reaction Potential to Response Latency" (PSYCHOL. REV., 1949, **56**, 208–223) equations (1′) and (1) are incorrect and should read as follows:

$$\bar{E} = E_0 + (M_E - E_0)(1 - e^{-iN}) = f_1(N).$$